

**SERIAL CIRCUIT OF SOLAR CELLS WITH INTEGRATED  
SEMICONDUCTOR BODIES, CORRESPONDING METHOD FOR  
PRODUCTION AND MODULE WITH SERIAL CONNECTION**

Description:

5           The invention relates to a serial connection of solar cells having integrated semiconductor elements.

          The invention also relates to a method for the production of a serial connection of solar cells having integrated semiconductor elements.

          The invention also relates to a photovoltaic module with a serial connection of  
10   solar cells.

          In industry, there is an increasing demand for methods for the production of serial connections of solar cells. Particularly in the special field of photovoltaics where semiconductor particles are incorporated into a layer system in order to form a p-n junction, it is practical to combine areas of thin layers and semiconductor particles  
15   to form cells or arrays and to connect these cells in series so as to be able to tap higher voltages. The problem of the serial connection of solar cells having incorporated semiconductor particles, however, has not yet been satisfactorily solved.

          German patent application DE 100 52 914 A1, for instance, describes a semiconductor component system in which a semiconductor structure consisting of  
20   layers with incorporated semiconductor particles is completely punctured at predefined places. Insulated conductor pins are inserted into these holes that have a size of a few hundred  $\mu\text{m}$  and these pins are firmly connected to a conductive layer on the front. The serial connection of the arrays is achieved by installing conductor bridges, after which the arrays are electrically separated from each other at the end of  
25   the procedure. The disconnection points are encapsulated with insulating and concurrently adhesive materials.

In another embodiment, which is likewise described in German preliminary published application DE 100 52 914 A1, the approach taken during the production of the semiconductor component system is that different semiconductor component types (n-type material and p-type material) are applied alternately onto defined surface areas. Thus, areas with positive or negative electrodes are alternately formed on one side of a system, and these electrodes can be connected in series by an integrated connection. For this purpose, the electrode layers are interrupted alternately on the top and on the bottom. The placement of different semiconductor component types in order to create a surface with different electrodes, however, is an expensive method.

Therefore, the objective of the invention is to provide a method for the production of serial connections of solar cells having integrated semiconductor elements that can be carried out with just a few simple process steps.

Moreover, it is the objective of the invention to provide a serial connection of solar cells having integrated semiconductor elements that is produced with just a few process steps that are simple to carry out.

Furthermore, it is the objective of the invention to provide a photovoltaic module with serially connected solar cells.

According to the invention, this objective is achieved by the features of claims 1, 22 and 26. Advantageous refinements of the invention can be gleaned from the subordinate claims.

In the method according to the invention for the production of a serial connection of solar cells having integrated semiconductor elements, one or more conductive elements and spherical or grain-shaped semiconductor elements are incorporated into an insulating support layer according to a pattern, whereby the

elements protrude from the surface of the support layer on at least one side of the support layer, and the pattern calls for at least one continuous separation line having a width B consisting of conductive elements. The areas next to a separation line or between several lines are fitted with semiconductor elements.

5 In an especially preferred embodiment of the invention, the pattern in the support layer provides that a distance exists between a separation line and an area that is fitted with semiconductor elements, so that, next to a separation line, a thin strip is formed into which separation cuts can be made without the conductive elements or the semiconductor elements being touched and likewise being cut. It is also possible  
10 not to have any distance so that the separation cuts are made in such a way that, as a result, parts of the conductive elements and/or of the semiconductor elements are cut off.

The elements incorporated into the support layer can be, for example, elements made of solid material or else coated substrate cores. Examples of  
15 conductive elements can be, for example, particles made of a conductive material or particles coated with a conductive material. In a preferred embodiment of the invention, the conductive material is copper. In another especially preferred embodiment of the invention, particles made from I-III-VI compound semiconductors or substrates coated with I-III-VI compound semiconductors are used as the  
20 semiconductor elements, so that the designation "semiconductor element" can refer to any element in which one constituent is a semiconductor material.

In another embodiment of the invention, the conductive elements are formed by one or more strips. This has the advantage that a continuous separation line can be created. Furthermore, it has proven to be advantageous to incorporate a conductive  
25 element in the form of a paste into the support layer. This is especially advantageous

when the support layer is a matrix with recesses for elements that are to be incorporated. Thus, the conductive paste can be applied onto one side of the matrix and can be pressed through the recesses to the other side of the matrix so that both sides have conductive separation lines that are contacted all the way through the support layer.

According to the invention, parts of the semiconductor elements are removed from one side of the support layer. This is done in order to expose a surface area of the semiconductor element that is to be contacted with the back contact of the solar cell. This is preferably a back contact layer that was deposited onto the semiconductor element below a semiconductor layer so that removal of the semiconductor layer is necessary. Furthermore, a back contact layer is applied onto the side of the support layer on which the semiconductor elements have been removed and a front contact layer is applied onto the other side of the support layer. The front contact layer and the back contact layer consist of a conductive material.

In order to produce a solar cell, depending on the envisaged embodiment, other function layers can be applied, which can include, for example, a buffer layer made of CdS, intrinsic zinc oxide and/or a transparent conductive oxide (TCO) layer. In another especially preferred embodiment of the invention, in addition to a back contact layer and a semiconductor layer, the semiconductor elements comprise other function layers, which can likewise include a buffer layer made of CdS, intrinsic zinc oxide and/or a TCO layer.

In another process step, two separation cuts are made along a row of conductive elements, whereby a first separation cut is made in the front contact layer and a second separation cut is made in the back contact layer. Here, the separation

cuts are on different sides of the appertaining separation line consisting of conductive elements, and they penetrate the back contact layer all the way to the support layer.

In an especially preferred embodiment of the invention, the row of conductive elements is essentially straight and extends between two edges of the support layer that are opposite from each other. However, the pattern of separation lines consisting of conductive elements and areas between them in the form of solar cells can be selected freely so that, for instance, curved separation lines are also possible.

The conductor elements and semiconductor elements can be, for example, scattered on and then pressed in. In an especially preferred embodiment of the invention, the spherical or grain-shaped elements are incorporated into a matrix of a support layer having prepared recesses for the elements. The elements can be incorporated into the support layer, for example, by means of a heating and/or pressing procedure. Various physical vapor deposition (PVD) and/or chemical vapor deposition (CVD) methods or other methods that have been adapted to the type of the layer in question can be used in order to apply the front contact layer and the back contact layer. If, for example, a conductive adhesive is used, brushing on or spreading on the adhesive has proven to be advantageous.

The method according to the invention makes it possible to generate a serial connection in which the current flows through an area of semiconductor elements of the front contact layer into the separation line consisting of conductive elements. The further flow of the current out of the conductor elements into the next area of semiconductor elements of the front contact layer, however, is prevented by a first separation cut so that the current flows via the conductive elements into the back contact. Here, the current flow through the back contact is prevented by a second separation cut in the back contact. Thus, between the separation lines consisting of

conductive elements, areas are formed that function as solar cells and that are connected in series with each other.

For this purpose, the serial connection of solar cells having integrated semiconductor elements has at least one insulating support layer in which conductive elements and spherical or grain-shaped semiconductor elements are incorporated according to a pattern, whereby the elements protrude from the layer on at least one side of the support layer. The pattern calls for least one continuous separation line having a width B consisting of conductive elements, whereas the areas next to a row or between several rows are fitted with semiconductor elements.

The serial connection also has a front contact layer and a back contact layer, whereby the back contact layer lies on the side of the support layer on which parts of the semiconductor elements have been removed. In each case, two separation cuts are made along a separation line consisting of conductive elements, whereby a first separation cut is made in the front contact layer and a second separation cut is made in the back contact layer. The separation cuts are on different sides of each row of conductive elements, and they penetrate the back contact layer all the way to the support layer.

When the serial connection is produced with the method according to the invention, on the side of the support layer on which the back contact layer of the solar cell is arranged, at least one of the spherical or grain-shaped semiconductor elements has a surface via which a direct contact is established between the back contact layer of the solar cell and a back contact layer of the semiconductor element. If the semiconductor elements are, for example, a substrate coated with a back contact and with a semiconductor, then the coating is removed from the semiconductor elements to such an extent as to form a surface consisting of back contact that can be contacted

with the back contact layer of the solar cell. If, in addition to a back contact layer and a semiconductor layer, the semiconductor elements have other function layers, then these were likewise removed so as to expose a surface consisting of the back contact.

The essential advantage of the serial connection according to the invention of solar cells and of the appartaining method for its production lies in the simple configuration of the connection of the solar cell areas, which calls for only a few processing steps. The requisite conductive elements can be incorporated in various forms and in different ways and the creation of the separation cuts is likewise a simple process step.

If spherical or grain-shaped elements are used, these can be incorporated with the same method as the semiconductor elements so that no additional methods or devices have to be developed and implemented for this purpose. If, for example, a paste that is applied onto a support matrix having recesses is used as the conductive element, then two separation lines that are joined via the support layer can be created in a simple manner. Moreover, the additional material requirements are low since only conductive elements have to be incorporated. The separation cuts that are made do not interfere with the overall arrangement since the weakening of the overall structure is very slight.

Further advantages, special features and practical embodiments of the invention can be gleaned from the subordinate claims and from the presentation below of preferred embodiments making reference to the figures.

The figures show the following:

Figure 1 in illustrations (a) to (c), the embedding of spherical semiconductor and conductor particles into a support layer;

Figure 2 in illustrations (a) to (c), the structure of front contact layers and back contact layers;

Figure 3 in illustrations (a) to (b), the serial connection according to the invention of solar cells having integrated semiconductor particles; and

5 Figure 4 an especially preferred embodiment of a shingle-like connection of several serial connections.

Illustrations (a) to (c) of Figure 1 show the incorporation of spherical or grain-shaped conductive elements 20 and semiconductor elements 30 into an insulating support layer 10. It has proven to be advantageous here to use a flexible film as the support layer. The support layer preferably consists of a thermoplastic material into  
10 which the conductive elements can be pressed. Polymer has proven to be especially practical and it can be, for example, a polymer from the group comprising epoxides, polycarbonates, polyesters, polyurethanes, polyacrylics and/or polyimides.

The embedded elements are preferably spherical or grain-shaped particles with  
15 conductive or semiconductive properties. In addition to the pure spherical shape, the elements can also have irregular shapes like those of grains having any contour. These also include, for example, cubes, parallelepipeds or pyramids. Therefore, spheres or grains made of conductive materials such as copper can be used as the conductive elements 20. In another especially preferred embodiment of the invention, the  
20 conductive elements are incorporated in the form of strips or a paste in the shape of a separation line.

The semiconductor elements consist completely or partially of suitable semiconductor materials used in photovoltaics. In an especially preferred embodiment of the invention, the semiconductor materials come from the class of the I-III-VI  
25 compound semiconductors, including for instance, copper indium diselenide, copper



indium disulfide, copper indium gallium diselenide or copper indium gallium diselenide disulfide. In another embodiment of the invention, the semiconductor elements consist of silicon semiconductors. These can be semiconductors made of solid material or substrate cores coated with semiconductor materials.

5           The conductive elements and the semiconductor elements are incorporated into the support layer 10 in such a way that they protrude from the surface of the layer on at least one side of the support layer. For this purpose, the elements can be applied, for example, by means of scattering, dusting and/or printing, after which they can be pressed in. In order to press the elements into the support layer, it can, for instance, be  
10   heated up. The elements can be arranged into a desired pattern, for example, using an auxiliary means, and in this manner, placed onto or into the support layer.

          In an especially preferred embodiment of the invention, the elements are incorporated into a prepared matrix of a support layer in which there are recesses into which the appertaining elements are inserted. In order to attach the elements to the  
15   support layer, a heating and/or pressing procedure can be carried out. For example, if a paste is used as the conductive element, the paste can be applied onto desired areas of the matrix and pressed into the recesses located there. The paste can be spread on the back of the support layer so that a separation line is formed on both sides of the insulating support layer which are connected to each other by the recesses.

20           The conductive elements are incorporated into the support layer according to a pattern that calls for at least one essentially straight separation line having a certain width B consisting of conductive elements 20. In this context, the fact that the row is essentially straight means that slight deviations from a straight line are also comprised. If a geometrically different delineation between individual solar cells is to be made

for certain applications, a different course of the rows of conductive elements can be selected such as, for example, curved separation lines.

Preferably, the separation line consisting of conductive elements extends between two edges of the support layer 10 that are opposite from each other. The width of the rows of conductive elements is preferably in the order of magnitude of  $B = 10\text{ }\mu\text{m}$  to 3 mm and, depending on the dimensions of the conductive elements employed, is defined by one or more conductive elements. In an especially preferred embodiment of the invention, the width of the separation lines is between  $10\text{ }\mu\text{m}$  and  $30\text{ }\mu\text{m}$ . If spherical or grain-shaped particles are used as the conductive elements, the width of the separation lines is a function of the diameter of the particles employed. Consequently, the width of the separation lines can also be in the order of magnitude of one or more diameters of a conductive sphere, especially between  $10\text{ }\mu\text{m}$  and  $500\text{ }\mu\text{m}$ .

Depending on the desired width of a solar cell that is to be connected, a support layer is divided into appropriate areas by several rows of conductive elements. The areas next to a separation line or between several separation lines are fitted with semiconductor elements. The width of a solar cell thus limited is preferably in the order of magnitude of 1 mm to 3 cm. In an especially preferred embodiment of the invention, the width of a solar cell is between 3 mm and 5 mm. The width of a support layer with a serial connection thus formed is preferably in the order of magnitude of 5 cm to 30 cm, whereby it has proven to be especially advantageous to have strip-like modules consisting of several serially connected solar cells that preferably have a width of approximately 10 cm.

The illustrations (a) to (c) of Figure 2 show the formation of the layer structure for the production of a solar cell having integrated semiconductor elements. In an

especially preferred embodiment of the invention, as a first step, material is removed from one side of the support layer 10. This side is removed down to a layer thickness at which parts of the incorporated elements have likewise been removed. The areas of the elements that have likewise been removed are shown in illustration (a) by the remaining contours of two conductive and semiconductor elements shown by a broken line. The removal of the support layer, however, can also take place at other points in time that precede the application of a later back contact 50 on this side.

In another embodiment of the invention, after the incorporation, the semiconductor elements protrude from one side of the support layer to such an extent that parts of them can be removed without a simultaneous removal of the support layer being necessary. The conductive elements, the semiconductor elements and/or the support layer can be removed, for example, by mechanical methods such as grinding, polishing, chemical or wet-chemical methods (processes) such as etching, photolithography or thermal energy input, for instance, by means of lasers or radiation with light having a suitable wavelength or wavelength range or by other thermal methods.

The extent of the removal depends primarily on the semiconductor elements employed. If, for example, spherical or grain-shaped substrate cores are used, which are coated at least with one back contact layer and with one semiconductor layer, the removal is carried out until the back contact layer of the particle is exposed in order to establish the contact with the back contact of the solar cell. In an especially preferred embodiment of the invention, the semiconductor elements are glass substrate cores that are coated with a back contact made of molybdenum and with a semiconductor. In this case, the removal of the support layer is carried out down to a layer thickness in which the molybdenum layer of the elements is exposed.

In this context, the removal also depends on whether all of the semiconductor elements are situated at equal depths in the support layer. If the semiconductor elements are embedded at different depths or if the size of the elements varies, then the possibility exists that not all of the semiconductor elements will have their coating removed down to their back contact layer.

In another process step, a back contact layer 50 is applied onto the side of the support layer 10 on which at least parts of the semiconductor elements have been removed. Conductive substances such as metals are used as the material for this back contact. It is also possible to use transparent conductive oxides (TCOs) or substances from various polymer classes. Especially suitable materials are, for example, epoxy resins, polyurethanes and/or polyimides that have been provided with suitable conductive particles such as carbon, indium, nickel, molybdenum, iron, nickel chromium, silver, aluminum and/or the corresponding alloys or oxides. Another possibility comprises intrinsic conductive polymers. These include, for example, polymers from the group of the PANis. The back contact can be produced by means of PVD methods such as sputtering and evaporation coating or CVD methods such as PE-CVD or MO-PVD or else with another technique that is adapted to the back contact material.

In another process step, a conductive front contact layer 40 is deposited onto the side of the support layer on which no processing of the elements was carried out. This can also be done with PVD or CVD methods as well as other methods that are adapted to the front contact material. Various transparent conductive oxides (TCOs) such as, for instance, aluminum-doped zinc oxide (ZnO:Al) (also called AZO), indium tin oxide (ITO) or fluorine-doped tin oxide (SnO<sub>2</sub>:F) can be used as the material for the front contact. It has proven to be advantageous to use a transparent

front contact whose transmission is preferably adapted to the semiconductor in question.

Other function layers can be deposited before and/or after the deposition of a front contact and/or a back contact. These include, for example, a buffer layer made of CdS, intrinsic zinc oxide and/or another TCO layer. In an especially preferred embodiment of the invention, these function layers have already been deposited onto the semiconductor elements employed so that there might not be a need for another deposition procedure in order to produce a solar cell.

As another essential process step, two separation cuts 60 and 61 are made along a row of conductive elements as is shown in illustration (a) of Figure 3. Here, a separation cut 60 is made into the front contact layer 40 and a separation cut 61 is made into the back contact layer, whereby said separation cuts lie on different sides of the row of conductive elements 20. The separation cuts can be made using methods such as cutting, scoring, thermal energy input such as, for example, laser cutting or else by means of photolithographic processes.

In an especially preferred embodiment of the invention, the separation cuts thus created are filled up with an insulating material in order to achieve the flattest possible surface of the solar cell connection. However, this step is optional since the requisite depth of the separation cuts 60; 61 is very small due to the fact that the thin front contact and back contact layers are in the  $\mu\text{m}$  range.

Once the procedure has been completed and all deposition and separation steps have been carried out, the resulting layers with the semiconductor elements constitute a serial connection of solar cells that can be used in a photovoltaic module. Depending on the embodiment of the photovoltaic module, it can comprise one or more serial connections. The resultant current course is indicated in illustration (b) of

Figure 3 by several arrows. In the embodiment shown, the negative front contact is on the top whereas the positive back contact is on the bottom. The current flows via the semiconductor element 30 in the front contact into the conductive element 20 and from there into the back contact 50, since a further current flow is prevented by the first separation cut 60. The current flow through the back contact 50 is prevented by the second separation cut 61.

In an especially preferred embodiment of the invention, such a serial connection is joined to at least one other corresponding serial connection so as to form a larger module. This is done, for example, in that the individual serial connections are configured so as to be strip-like with a width in the order of magnitude of 5 cm to 30 cm and the sub-modules thus formed are laid over each other at the edges like shingles. This is shown in Figure 4. Hence, a back contact comes to lie on a front contact and the individual modules are, in turn, connected in series. The contacting between each front contact layer and back contact layer can be done by means of a conductive adhesive such as silver epoxide.

## List of reference numerals

	10	support layer, film
	20	conductive element, conductor element
5	21	separation line
	30	semiconductor element, spherical or grain-shaped
	40	front contact layer
	50	back contact layer
	60, 61	separation cuts